

DIRECTIONAL DRILLING

1. General. Installation of pipelines through the levee embankment using directional drilling technology is prohibited. Installation of pipelines through a flood control project foundation should follow the requirements described in this topic. Levee design for underseepage conditions is based on permeability values and blanket thickness of the respective zones of clay, silt and sand. Any blanket penetrations potentially compromise the integrity of the foundations to resist piping of fines. Voids can exist in the annular spaces between the drill hole and the pipe. Fracturing of the foundation blanket can be caused by excessive pressure heads in and at the base of the blanket. These mechanisms create potential seepage paths in and through the blanket. The seepage path continues below the levee in the foundation sands. Little or no resistance in these void spaces can allow for uncontrolled flow during flood stages, resulting in piping that removes materials from below the levee or blanket and eventually leads to collapse of the levee. If this occurs during flooding conditions catastrophic flooding of the protected area can occur. The following recommendations are based on a study performed at U.S. Army Corps of Engineers, Waterways Experimental Station. The study is presented in the report: CPAR- INSTALLATION OF PIPELINES BENEATH LEVEES USING HORIZONTAL DIRECTIONAL DRILLING, published in April 1998.

2. Design considerations.

2.1. Geotechnical investigations. Detailed subsurface investigations should be performed along the proposed directional drilling site to determine the stratigraphy. Many of the key parameters for a project, including limiting pressures, setback distances, and depth of cover, depend on soil properties and geotechnical data gathered during preconstruction geotechnical investigations or data obtained from the design of the flood protection project by the COE .

2.2. Drilling Fluid Pressures. There are legitimate concerns associated with the fluid pressures used for excavation during the horizontal directional drilling process and the risk of hydraulic fracturing. Reasonable limits must be placed on maximum fluid pressures in the annular space of the bore to prevent inadvertent drilling fluid returns to the ground surface. However, it is equally important that drilling pressures remain sufficiently high to maintain borehole stability, since the ease with which the pipe will be inserted into the borehole is dependent upon borehole stability.

2.2.1 Maximum allowable drilling fluid pressure. Limiting borehole pressures are a function of pore pressure, the pressure required to counterbalance the effective normal stresses acting around the bore (depth), and the undrained shear strength of the soil. It is necessary for the pressure in the annular space of the bore to remain below the maximum allowable pressure throughout the drilling process to minimize the potential for initiating plastic yield and losing drilling mud to the surface. To establish the maximum allowable mud pressure, the internal friction angle, the shear modulus of the soil, the depth of the soil cover, and the initial pore pressure should be used.

2.2.2. Minimum required drilling fluid pressure. Unreasonably low borehole pressures cannot be maintained without severely hindering the drilling process and, in some cases, making the pipe installation impossible. The drilling mud pressure must be maintained above the groundwater pressure to prevent collapse of the borehole.

2.2.3. Monitoring Drilling Fluid Pressures. During the drilling process, the pressure in the borehole must be monitored to ensure that the operational drilling pressures remain within the safe limits, as calculated with the recommended methods. A pressure gauge has to be located at the mud pump to measure mud pressures within the drilling stem. However, there is a significant amount of head loss due to the flow through the drill stem and the rotational movement of the drilling mud caused by the abrupt change in flow direction as it exits the drilling stem into the annular space. Instead of monitoring the pressure in the drill stem and estimating the head losses through the drill stem and nozzles, it is highly recommended that the pressure in the annular space be monitored, since the pressure in the borehole ultimately affects the stability of the bore. It is requested that an external pressure measuring device be installed when drilling beneath flood protection structures. In addition, pressures should be monitored and recorded at the drill stem and in nearby piezometers to monitor the radial effect of the drilling process. Monitoring should include preconstruction and excess pressures resulting from the drilling process dissipate. Plans for monitoring and controlling drilling fluid pressures and for avoiding inadvertent returns should be submitted for review. The limiting pressures should be estimated prior to construction and clearly stated in the contract documents or in the Contractor's submittals.

2.3. Setback Distances. Determination of appropriate setback distances is very important with respect to damage of the levee toe and seepage and uplift pressures at the point where the top stratum is penetrated by the drill string. Levee toe stability is not the controlling factor under normal circumstances but should be checked in the design as a precaution. However, seepage is a significant concern and must be addressed on a case-by-case basis as seepage is highly dependent on levee geometry, high water level, the material of the top stratum, and the material in the substratum. The setback distance can be established based on seepage analyses, using measured soil properties and engineering characteristics determined from geotechnical investigations. If no seepage analyses are performed, the following recommendations should be considered.

2.3.1. If construction plans and specifications are not supported by borings made at the project site, the pipeline must be at its maximum depth at least 300 feet landside from the center line of the levee on the landside.

2.3.2. If plans are supported by borings at the project site, the drill rig must penetrate the substratum at least 300 feet from the levee center line on the landside and must not exit the substratum or penetrate the top stratum any closer than 300 feet riverside of the levee center line.

2.4. Levee toe stability. External drilling pressures do not pose a serious concern for levee stability if

the pipeline is designed at an appropriate depth, proper drilling procedures are employed, and drilling pressures are monitored accordingly. When designing the depth of the pipeline, it is important to consider that the drilling fluid pressures may well exceed the maximum allowable drilling fluid pressure near the entry and exit locations due to the shallow depths, resulting in limited inadvertent returns. Because reasonable fluid pressures must be maintained to initiate and complete the bore, "excessive" pressures are necessary in these shallow zones. Therefore, the entry and exit locations should be located such that these zones do not threaten the safety of the levee.

2.5. Penetration of the top stratum. The permeability of the top stratum and the difference in permeability between the top impervious blanket and the aquifer beneath it are critical factors for the hydraulic gradient beneath a flood control structure. If a larger contrast exists between top stratum and substratum permeabilities, the computed setback distances may be quite high. At a minimum, it is recommended that the pipeline should not penetrate any berm of the levee on either side. In cases where the difference in permeabilities between the top and bottom strata are several orders of magnitude apart, it is important to establish a reasonable distance where seepage and uplift pressures will have negligible effects on levee stability.

2.6. Depth of Cover. The minimum depth of cover should be established by the calculations for maximum borehole pressures and a comparison of those pressures and reasonable drilling pressures. In the case where the reasonable operational drilling pressure exceeds the maximum drilling pressure, the pipeline should be set at a deeper elevation to raise the maximum drilling pressure. Establishing a minimum setback distance at which the maximum depth of the bore is reached prior to the center line of the levee should not be necessary as long as drilling pressures are closely monitored and remain within the established limiting pressures.

2.7. Speed of Drilling. The speed of drilling should be controlled for several reasons. It may be difficult to maintain the planned line and grade if the advance rate is extremely high. If the drill veers offline due to the advance rate, the driller may decide to pull back a section and re-drill for position. Redrilling caused localized pressure bulbs that resulted in increased drilling pressures over longer time periods compared to one-pass drilling. Redrilling for position may be necessary; however, it is recommended advance rates be limited as a preventative measure against pressure buildup. It is extremely important to adjust the flow rate of the drilling mud when changing the speed of the drilling operation. This will limit the possibility of over pressurizing the borehole due to the total volume of mud that is pumped per drill pipe section.

2.8. Groundwater. The groundwater pressures tend to counterbalance drilling fluid pressures and reduce the potential for hydrofracture. When practical, it is recommended that the design depth of the pipeline should remain below the water table when drilling within a lateral distance of 25 feet from the levee toe.

3. Prevention of Seepage and Erosion Along Pipeline. Concerns have been expressed about the

potential for development of preferential seepage pathways along the pipeline annulus during flooding or high water stages. The high hydrostatic head and gradients could cause the drilling fluid and soil mixture to be flushed from the annular space. Seepage flows around the pipeline could produce high seepage velocities resulting in soil erosion and development of boils on the landside at the point where the installed pipeline penetrated the ground. The following recommendations for the design and construction measures that minimize or eliminate the potential for unacceptable seepage along the pipeline are provided.. These measures include:

3.1. Grouting of annular space and minimizing annular space. Grouting of the annular space with a cement or bentonite-cement grout mixture will expel the semifluid mixture of bentonite, soil, and water with a grout material that will set and provide a solid barrier against seepage flow along the annulus.

3.1.1 Grouting during pullback. One possibility is that a grout mixture with a delayed set time be pumped into the hole during the final reaming and pullback of the pipe to more effectively displace the bentonite based drilling mud mixture. Grouting during pullback reduces the risks of future development of seepage pathways. While filling the annular space with a low-permeability material is a desirable goal, the process of grouting during pullback is not recommended. Research and testing of grout materials with controlled delayed set times and grouting procedures should be required prior to such a recommendation due to the risks of failure to complete the pipeline installation. If for any reason the pullback was delayed beyond the initial set time, the partially installed pipeline could become grouted in place..

3.1.2. Grouting of the annular space upon completion of the bore. The grouting pressures required to expel the drilling fluid must exceed hydrostatic pressures because the drilling fluid pressure in the annulus must equal or exceed hydrostatic pressure. The grouting pressures must be lower than the overburden pressure or critical pressure required to initiate hydraulic fracturing. To increase the likelihood of uniform grout distribution around the pipe annulus, the use of perforated grout tubes attached to the pipeline has been suggested. After the grout is pumped through the tubes, they would be abandoned in place. This process would increase the difficulty and risk of failure of the pullback operation and could adversely impact corrosion resistance of the pipeline.

3.1.3. A grouting procedure is to insert grouting tubes as far as possible into the borehole after the pipe is pulled back. The grout mixture would be pumped into the annulus through these tubes until grout returned to the surface at the entry or exit of the pipeline. Grouting pressures must be carefully controlled to minimize risks of hydrofracture. This procedure is recommended as an added insurance measure at both ends of the pipeline.

3.1.4. The composition and hydraulic conductivity of the soil drilling fluid mixture should be tested prior to construction to determine the in-place resistance to seepage provided by the mixture. It may be determined that the hydraulic conductivity of the soil-bentonite-water mixture is sufficiently low (lower than the surrounding natural soil) to minimize potential for seepage along this pathway. These tests

should be performed using the actual drilling fluid mixture(s) planned for use on the project, with varying percentages of bentonite and natural soils to bracket the planned or expected field conditions. This approach would also necessitate field quality control tests to ensure that the drilling fluid mixtures used for construction were the same as those tested.

3.2. Seepage blankets or berms (antiseepage devices). Seepage blankets and berms may be used to increase the factor of safety against piping and erosion along the landside toe of levees. Some form of these features could be used on the landside entry and exit points of pipeline crossings for the same purpose, i.e., to reduce the risk of piping and erosion along the pipeline that could undermine the levee or its foundation. It is recommended that a seepage analysis be performed during design of the crossing. If the hydraulic gradient at the landside entry/exit points exceeds the maximum allowable gradient, a landside seepage blanket should be evaluated. To achieve its design function, the blanket would not have to extend great distances on either side to the pipeline, but could rather be a small localized surface feature with gentle slopes to aid in levee maintenance. The evaluation should be performed using actual soil properties, site conditions, and geometry.

3.3. Riverside cutoffs or collars. Riverside cutoffs or seepage collars may be considered for projects with exit points on the riverside of levees. For projects that enter and exit on the landside of opposite bank levees, riverside cutoffs are obviously not applicable. Seepage barriers, rings, or cutoffs are addressed in EM 1110-2-1913, DESIGN AND CONSTRUCTION OF LEVEES. If considered, seepage collars should be evaluated during design using actual site conditions, soil properties, and geometry. The materials and mixture should ensure low hydraulic conductivity, low shrinkage, and long-term stability. Placement and compaction must ensure intimate contact around the full pipeline circumference, without damage to the pipe. Laboratory tests of the hydraulic conductivity of the materials and mixture should be performed. In addition, hydraulic conductivity tests of the system may be beneficial.

4. Closure Devices. Closure devices are required for all pipes that penetrate the embankment or foundation of a levee. Closure devices (valves) could serve a critical purpose in an emergency and should be considered with regard to pipelines beneath levees. Valves are required for liquefied petroleum pipelines by U.S. Department of Transportation regulation, Part 195, Section 260(e), at water crossings longer than 100 feet. Valves are not required on gas pipelines since there is no danger of spills.

5. Relief Wells. Relief wells are not considered necessary under normal circumstances. The objective of proposed relief wells has been to vent the high drilling fluid injection pressures and avoid fluid pressures that exceed earth and groundwater pressures. The directional drilling process uses relatively high drilling fluid pressures and flow rates to the injection nozzle. These reported pressures have caused concerns about hydrofracturing. However, these pressures are quickly attenuated within a short distance of the nozzle. Relief wells may be effective for dissipating high seepage pressures on the landside toe of levees during high water events.

6. All excavation and backfill for the proposed utilities or miscellaneous support structures should be accomplished in accordance with the Section: EXCAVATIONS AND BACKFILL
7. Pervious backfill is not allowed within the critical area of the levee system. Permanent penetrations through the blanket materials can only be justified based on underseepage analysis. Pipes located within the critical area must have watertight joints.
8. Connections, type of bedding, or other structures within the critical area should meet applicable COE criteria as listed in the topics PIPING and STRUCTURES. Pipe selection and analysis should be checked referencing EM 1110-2-2902, CONDUITS, CULVERTS, & PIPES. .
9. Any evidence of impending danger to the flood protection project should be immediately forwarded to the drainage district. Should anything go wrong, the drilling operation should immediately cease, all equipment should be pulled and the entire progress of drilling should be grouted. Sufficient grout should be available on site to seal the hole immediately.
10. Any surface evidence of drilling fluid return or any surface fracturing will require complete excavation and removal of the affected foundation blanket and flood protection levee. Levee and blanket replacement should meet COE design standards.
11. Emergency notification and contingency plans should be explicitly stated in the plans,
12. Recommended References.
 - 12.1. CPAR-GL-95-2, GUIDELINES FOR TRENCHLESS TECHNOLOGY, U.S. Army Corps of Engineers, Waterways Experimental Station, Sept. 1995, includes the following:
 - (1) Guidelines for directional drilling.
 - (2) Curred in place pipes and formed pipes.
 - (3) Mini-horizontal directional drilling.
 - (4) Microtunneling
 - 12.2. CPAR-GL-98-1, INSTALLATION OF PIPELINES BENEATH LEVEES USING HORIZONTAL DIRECTIONAL DRILLING, U.S. Army Corps of Engineers, Waterways Experimental Station, April 1998, includes recommendations for design and construction of directional drilling.
 - 12.3. EM 1110-2-2902, CONDUITS, CULVERTS, & PIPES, includes piping system requirements in the critical area of flood control projects.